PRECISION AGRICULTURE DEVELOPMENT IN TAIWAN

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ABSTRACT

The objective of this paper was to report the development of precision agriculture for rice crop production in Taiwan during past five years. Three multi-disciplinary research teams have been organized for the purposes of developing techniques required for monitoring growth status and environmental conditions for rice crop; integrating the elements necessary for fertilization recommendation system and pest management system; and developing machinery for yield monitoring and mapping system, field-based remote sensing system, variable-rate pesticide spraying system, and variable-rate fertilizing system. More than fifty researchers have engaged in the precision agriculture project of US$3.5 millions budget during past five years.
Keywords. Precision agriculture, GPS, GIS, Rice, Taiwan

1. INTRODUCTION

Precision agriculture (other terms have been used, such as precision farming, satellite farming, in-field site-specific crop production, and variable rate application technology) can be applied in the entire crop production cycle, from pre-planting to harvesting operations. Up to date and future technology such as geographic information system (GIS), global positioning systems (GPS), and computer field mapping coupled with on-board electronic controls, will provide new levels of automation for agriculture to improve soil testing, tilling planting, fertilizing, spraying, crop scouting, and harvesting efficiencies.

Some research results as stated in followings have reported the potential of adopting precision farming (Auernhammer and Schueller 1999; Kuhar, 1997; Meyer et al., 1997; Reetz, 1999). Crop scouting uses satellite images and photographs taken from aircraft to identify patches of weed, drainage problems, insect stress, and other crop conditions. The fields also can be surveyed from pickup, tractor, and combine cabs and on foot. Soil test results can be used to produce soil maps from the sampling position information provided by GPS. The seedling rate and planting depth for obtaining optimum planting population and germination rates can be regulated according to soil characteristics revealed in soil maps. Information provided by soil sensor technology and GPS will instruct machines to vary tillage depth and plant residue left on the soil surface in order to reduce soil compaction and optimize soil temperature and moisture content for crop growth in conservation tillage systems.

Some high-tech equipment for assessing field conditions can be applied in selectively applying chemicals and fertilizers to a specific site. Automatically controlled sprayers can vary the amount of pesticide applied (patch spraying) while driving across the field, being guided by a weed map obtained from remote sensing. Weed infestations or crop health images can be acquired from satellites, airplanes, or remotely piloted vehicles. Yield measurements document the result of previous farm activities and can be used to plan for the coming crop. Merging the yield sensor, moisture sensor with GPS in crop harvesting operations will record yields on a site-specific basis and produce a yield map through the use of mapping software on the office computer.

Precision agriculture will manage for each crop the input of fertilizer, limestone, herbicide, seed, and etc. on a site-specific basis, to reduce waste, increase profits, and maintain the quality of the environment. Technology such as GIS, GPS, electronic sensors, controllers, and sophisticated software are required to successfully and economically implement precision agriculture on large areas of mechanized farm land which have yield variation among plots due to different fertility status of the soil, insect pressure, and poor field drainage.

Although the average farmland is about one hectare in Taiwan, in response to Taiwan (Republic of China) President Lee Teng-Hui's encouraging speech in the National Agricultural Meeting, a preliminary study was initiated by National Taiwan University in 1998 to invite related engineers and scientists to investigate the feasibility of applying precision agriculture system in Taiwan. Policy of adopting precision agriculture in the future was then recommended in 1999.

In 1999, Taiwan Agricultural Research Institute (TARI) initiated a pilot project on precision farming system for rice crop in Taiwan. Three multi-disciplinary research teams have been organized for the purposes of developing techniques required for monitoring growth status and environmental conditions for rice crop; integrating the elements necessary for fertilization recommendation system and pest management system; and developing machinery for yield monitoring and mapping system, field-based remote sensing system, variable-rate pesticide spraying system, and variable-rate fertilizing system. More than fifty researchers have engaged in the precision agriculture project of US$3.5 millions budget during past five years. Most of the studies were carried out at experimental rice field of about 15 hectares located in Taiwan Agricultural Research Institute. The experimental unit was about 0.5 hectare.

The objective of this paper is to present the up to date information in line with Taiwan precision agriculture development in the areas of studying remote sensing techniques, nitrogen content in rice plant, soil nutrient and fertilization, and farm machinery during past five years.

2. APPLICATION OF REMOTE SENSING TECHNIQUES

SPOT and Duncan MS3100/CIR imagery were adopted for the study of rice growth status and yield monitoring. Remote sensing satellite images are characterized by economical, fast and wide viewing ability. The full-growth-periods spectral responses of rice were characterized by NDVI distribution derived by SPOT bands, and the NDVI responses of normal and leaf blast infected rice plants were compared. The results showed that both NIR and NDVI indices reached the maximum in panicle formation to grain filling stage, while their values were lower in the leaf blast infected rice as compared to the normal plants. Since SPOT image is lack of thermal channel, the Landsat data were used to construct the regression function between NDVI and surface temperature for studying evapotranspiration over rice crop fields (Yang and Lin, 2000; Yang and Lin, 2002).

The dynamic changes of canopy reflectance spectrum measured by portable spectroradiometer (LI-1800; 400-1100 nm) were least during booting stages. A multiple regression model, constituting of band ratio (NIR/R, NIR/G) calculated from green (G), red and near infrared (NIR) portions of canopy reflectance spectrum, was able to estimate rice yields from different crop years. Validation tests, using data of 1st crop, 2001 collected from PA experimental field of TARI, indicated positive correlation (R^2 = 0.84) between model prediction and actual measurements.

Hyperspectral resolution (reflectance spectra 350-2500nm) from rice canopy infected with various percentages of leaf blast and different levels of leaffolder were collected and analyzed using a portable spectroradiometer (GER-2600, Geophysical & Environmental Research Corp.). The maximum correlation coefficient between reflectance and percent infection or levels of infection (six levels) was located at 1436 nm (r=0.982) for the blast and at 2327 nm (r=0.946) for leaffolder.

For highly mobile and capable of providing high resolution images, an airborne multi-spectral observation system was studied to detect and identify the different growth periods of the rice and the abnormal spectral signatures of rice crop caused by stress conditions such as pest, disease, weeds and drought. The ground-based imagery can be used to distinguish the growth variation by the different rates of nitrogen fertilization.

The setup of database management system of spectral reflectance for near-surface rice paddy was based on client-server of 2-Tier or 3-Tier, which can be run with web environment.

2.1 TECHNIQUES FOR DETECTING NITROGEN CONTENT IN RICE PLANTS

Promising results have been achieved in developing remote sensing technique and identifying spectral characteristics associated with nitrogen content of rice plants (fertilization treatments: 0, 60, 120, 180 kg/ha) and establishing their quantitative relationships. The vegetative and reproductive growth at non-nitrogen field was less than those at normal nitrogen field. Canopy reflectance spectral difference among nitrogen treatments could be easily identified by spectral differential techniques. Both portable spectroradiometer and multi-spectral imager were used to measure the reflectance characteristics of rice crops with different treatments of fertilization. The remote sensing system can be adopted for nondestructive measurement of nitrogen content in rice stalk. The best model of stepwise multiple linear regression was the first derivative of spectra with 5 wavelengths of 479, 623, 632, 715 and 1611 nm. A simplified hyperspectral imaging system was mounted on a mobile lifter allowing images taken at 15m above ground level.

2.2 ESTABLISHING DATABASES FOR SOIL NUTRIENT AND FERTILIZATION

Databases management for accurate assessing the spatial variability of soil and relating it to yield quantity and quality components were studied in past years. Rice nutrient spatial distribution and the soil variation data of the PA experimental farm were analyzed by co-kringing method to find the best relationship between rice nutrient and crop yields. The CERES rice model was calibrated and validated by using soil and phonological data of the PA experimental field so as to obtain quality algorithm in estimating site-specific optimum nitrogen input.

The research team also introduced EM38 electrical conductivity detector (Geonics Co.) to reconnaissance paddy fertility. As EMI readings were significantly correlated with soil exchange K content, EMI measurement can be expected to assess spatial variability of exchange K in field and adopted as references for differential application of K fertilizer. The EMI measurements of 100 samples collected in 0.5 ha paddy field only took 35 minutes. The incorporation with ESAP software provides distribution map of EC for determining soil fertility spatial variability.

2.3 DEVELOPING MACHINERY FOR RICE PRECISION FARMING

The machinery and tools for spraying system of boom sprayers, software integration of GPS/GIS system, variable-rate fertilizing machine, and yield monitor system for precision farming were developed and gained some promising results during past years studies in Taiwan (Lu et al., 2000; Lu, 2001).

Yield monitoring system was studied to measure the harvested crop over unit space and time and to present the geo-referenced unit production in graphical form for precision farming management. A five-row rice combine with 1.6m cutting width (Kubota R9101G) was remolded to install the yield monitor system, which includes flow sensor (Micro-Trak grain flow sensor CGS 2000), grain moisture sensor (DMC moisture sensor), ground speed sensor, run and hold sensor, data logger (Micro-Trak System grain sensor input TNGS-100; Data-Trak TNM-1000), and a display console (Grain-Trak TNY-4400). A local made GPS antenna (San Jose Navigation Inc. model DGPS-220, 1 m position error) was adopted in this system. Based on the information collected from these sensors, rice yield maps have been successfully produced by running mapping software. Although yield and moisture content of the harvested rice can be monitored at accuracy of 85-90%, further works are required to upgrade the accuracy of the yield monitoring system. Modification of the yield monitoring system is going to be completed in 2003. A genuine thresher system of YANMAR GC85 rice combine was converted to form a testing stand for studying performance of commercialized foreign yield monitor system and domestic made system.

A portable sensing device was developed by integrating multi-spectral imaging system, global positioning system and multi-functional carrier for the rice field application. Global positioning system was used with electronic maps for location identification in the PA rice field. Near infrared measurements of rice canopy in the field at ground level were analyzed to find relationship between reflectance spectra and crop growth characteristics (e.g. height, number of tillers, chlorophyll index etc).

A variable-six-rate fertilizing machine attached to a Kubota SPA85 rice transplanter for applying chemicals 8 to 10cm below soil surface was developed. The chemical was conveyed by an adjustable finger shaped block, which is driven by a programmable logic controller (PLC) based servomotor. A rotor moves back and forth to deliver chemicals. The rotor with concave slots is able to load chemical and drop chemical into soil. The average error for the variable fertilizing rate was less than 3%.

A boom sprayer manufactured by Zetor Co., Taiwan and a Pro-XR GPS/Beacon receiver and GPS antenna of Trimble Co., U.S.A. were adopted in developing precision spraying system. A spraying control box processes the signal from GPS and sends an output signal to electrical flow control valves for spraying. When the sprayer moves into a designated spraying area, the valves will be opened to allow the liquid flow through the valves to the nozzles.

An integrated software system for agricultural vehicle location and mapping using GPS/GIS technology has been developed to test the accuracy of the system when the selective availability error was removed. The software system was implemented under the Windows operating system. The rapid application development (RAD) programming C++ Builder was used for software integration. In order to incorporate the GPS information into the GIS system, the software development toolkit MapObjects for ArcInfo (Environmental Systems Research Inc., ESRI) was applied to create customized mapping and GIS functions that fulfill specific tasks and requirements. The GPS receiver was AgGPS 132 (Trimble, USA) which is a 12-channel GPS receiver that uses either free public or subscription-based private differential correction services to calculate sub-meter positions in real-time. The GPS receiver was linked to a portable computer via RS-232 serial interface. The NMEA-0183 output was read from the GPS receiver by the developed program and translated into vehicle coordinates for geographical mapping. Contour mapping algorithms was also developed to display the field conditions and information. A typical automatic vehicle location (AVL) and mapping test was studied. When the vehicle carrying the GPS system was at anchored status, the standard deviation of the x and y coordinates were 0.105 m and 0.291 m, respectively. When the coordinates were mapped to the GIS maps, another error source from the electronic map could be introduced to the system. However, our tests indicated that the global error was within 1 m.

3. CONCLUSION

Preliminary studies on diagnosing rice field crop during growing season through the utilization of satellite-based and remote sensing techniques and NIR spectrum were carried out successfully in past five years in Taiwan. The development of precision spraying system for boom sprayers, software integration of a GPS/GIS system, variable-rate fertilizing machine, and yield monitor system for rice crop were also conducted in past years. The future goals are to improve the accuracy and to implement precision agriculture system in Taiwan to improve the efficiency of crop production management.

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